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PHYSICS.—*Explorations in the superconducting state.*[1]

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In the early days of this Society, its leaders were in a large measure pioneer workers, blazing new trails into hitherto unknown territory. I need only list Henry in Electromagnetics, Langley in Aerodynamics, Dutton and Hayford in Isostasy, and in literal geographic exploration Powell, to remind you of their achievements. Today most of us spend our lives mapping with meticulous precision the rich provinces which they first opened up, and can only rarely venture as they did into unbroken fields, where the general nature of the phenomena is still unknown, where the basic concepts are still to be conceived, and where even a suitable language for an adequate description of events is yet to be invented. Nevertheless the call of the unknown still has a glamour for all scientists and it is, therefore, without apology that I propose this evening to give a further report of recent progress in one of the few remaining unexplored regions of physics.

When in 1908 Kamerlingh Onnes first liquefied helium, he opened the way into a large and most fruitful province. I say "large" advisedly for though the newly available temperature range, namely 2°K to 10°K, seems small when expressed in degrees, it is more properly regarded as extending over more than two octaves in absolute temperature. An equal journey by a factor of 5 from our room temperature of 300°K, if taken upward, will bring us to 1500° when all but the most refractory materials are melted, or if taken downward, will lead well below liquid air temperatures.

During the past few years Giauque, Debye, and other explorers have passed the boundaries set by the helium province to start operations in a still more remote region, but we shall limit our wanderings this evening to the nearer but still strange and mystic territory known as the liquid helium range.

This helium region contains many features which to the eye of the

[1] Address of the retiring president, delivered before the Philosophical Society of Washington, January 16, 1937. Publication approved by the Director of the National Bureau of Standards of the Department of Commerce. Received January 18, 1937.

physicist seem as bizarre and fantastic as the monsters with which geographical explorers used to ornament their maps. For one thing there is no fluid but helium and all profit must be based on its use. All other substances can here exist only in the solid state. Any leakage of air into the apparatus is dreaded not because of its oxidizing action but merely because the piping will be clogged by a plug of solid air. In this topsy-turvy land platinum and copper lose their utility as resistance thermometers and show a resistance which is almost independent of temperature, while on the other hand manganin and constantan are quite suitable for resistance thermometry. Another paradox shows up even in one of the very methods used for arriving at this wonderland. A strong vessel is filled with helium gas at a fairly high pressure and cooled to liquid hydrogen temperatures. The valve is then opened and after *half* of the helium has been allowed to escape, the vessel is found to be *two-thirds* full of liquid.

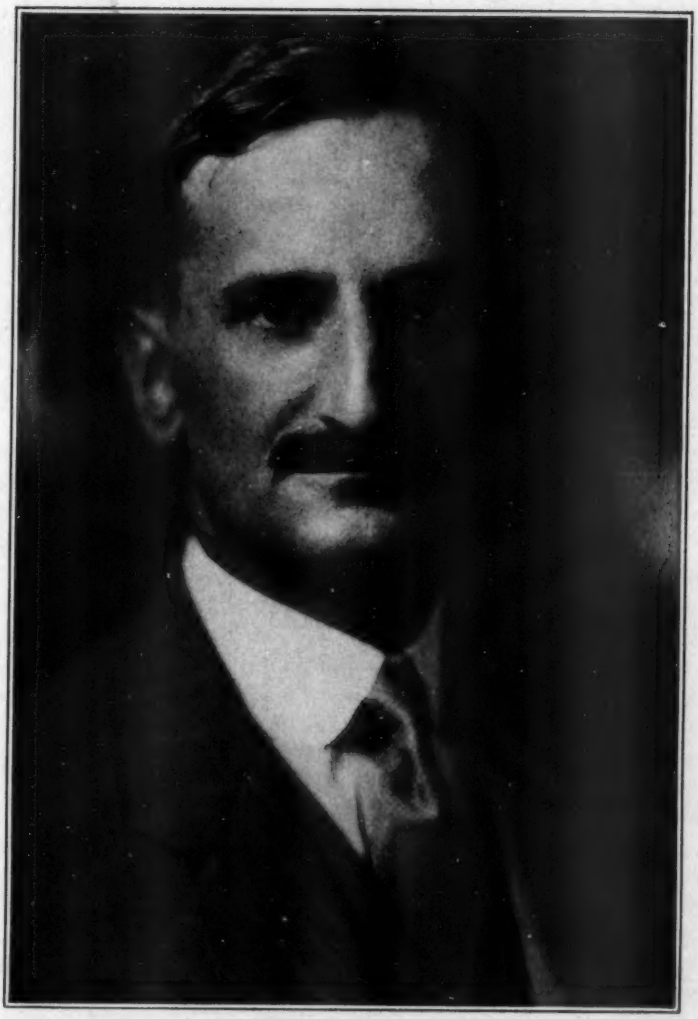
Just as the wanderer in the fairy story came upon a baffling mountain of glass in which mechanical friction was non-existent, so did Kamerlingh Onnes in 1911 find himself confronted by a wire of quicksilver in which electrical friction (i.e. resistance) was non-existent. It is of the more recent explorations in this range of glass mountains, or as Kamerlingh Onnes called it, the superconducting state, that I wish to talk this evening.

In the time available any attempt at a complete summary of the subject is out of the question, and I shall merely touch upon the more outstanding features of the pioneer findings and here and there venture some rather rash speculations of my own as to what may lie beyond the horizon. In opening a conference on the subject in 1935, McLennan (4)[2] characterized one phase of the situation by saying that "the experiments agree only in that the result is never quite what might be expected." If, therefore, my surmises turn out to be quite far from the truth, the present delightfully paradoxical atmosphere of the subject will not have been disturbed.

First, to refresh your memories, let me outline the earlier work in this field. Until 1923 all experimental work was confined to the Cryogenic Laboratory of the University of Leiden, but now explorers recruited from the far corners of the earth are working in laboratories at Berlin, Toronto, Oxford, Cambridge, Kharkov, and Washington.

The early work served to establish that the resistivity of a material in the superconducting state was exceedingly low. Recent experi-

[2] Numbers in parentheses refer to the bibliography at the end of the paper.



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ments (9) on Pb have shown it to be certainly less than 10^{-15} times its value at 0°C. If a wire having a resistivity equal to this upper limit were drawn down to a diameter of 1 micron, then to secure a resistance of 1 ohm it would require a length sufficient to encircle the earth 100 times. Many metals such as Hg, Pb, Sn, Tl, Ta show this property, though others, such as Au, Cu, Ag, Bi have not shown it at the lowest temperature at which they have thus far been tested. It is therefore still an open question whether or not superconduction is a common property of all metals. Many alloys which have at least one superconducting component are also superconducting, and even Au_2Bi becomes superconducting at 1.84°K, although neither of its constituents shows the phenomenon even at much lower temperatures. Still stranger is the fact that a number of compounds such as CuS, TiC, VN, ZrC, ZrB, etc., which are relatively very poor conductors of electricity at ordinary temperatures, become superconducting at helium temperatures. The list of superconducting materials grows almost daily and I will not attempt to give it in full here.

The early workers also discovered that if a sufficiently intense magnetic field was applied to a superconductor its resistance was restored. The requisite intensity of field is a function of temperature and is roughly proportional to the difference between the temperature of the specimen and the critical temperature at which it becomes resisting in the absence of a magnetic field. A similar limiting intensity was found for the current which the specimen could carry and still remain superconducting, and it was a very obvious suggestion on my part that these two limits should be connected by the relation that the critical current was of such a value that the magnetic field which it produced at the surface of the material was equal to the critical magnetic field. The truth of this relation has been confirmed experimentally (33) for Sn and Pb, and for 19 years the hypothesis was assumed to be generally applicable until it was found to be most certainly *not* true for Ta and several alloys by laboratory groups of one of which strangely enough I was a member.

It would be expected that such a tremendous change in one property of a material would be accompanied by corresponding changes in other properties. For a long time, however, no trace of any other changes could be found. More recently de Haas and Bremmer (5, 6, 7 and earlier papers) found that the thermal conductivity at temperatures well below the normal transition temperature is somewhat abnormal unless a sufficient magnetic field is applied to prevent the appearance of superconduction. In the case of Pb, In and Sn the onset

of the superconducting state, by the removal of an inhibiting magnetic field, decreases the thermal conductivity in direct contradiction to the Wiedemann-Franz relation, while with the alloy $PbTl_2$ the effect is strangely enough of the opposite sign.

A second property which has been found to be different in the superconducting state is the specific heat. Keesom and van den Ende have shown that for Sn and Tl the specific heat is about 50 percent greater when the material is in the superconducting state, and that in the absence of a magnetic field there is no latent heat of transition.

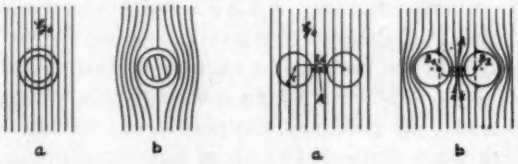

Fig. 1.—Expulsion of magnetic flux produced by cooling a lead tube (left) and a pair of tin cylinders (right) in the presence of a transverse external magnetic field which had been applied while the specimens were above their transition temperature; *a* before, *b* after, cooling.

A new era was begun by the publication by Meissner and Ochsenfeld in 1933 of the results of experiments (20) in which the magnetic field in the neighborhood of their specimens was measured, by a "flip coil," while the specimens were cooled through the transition temperature while in the presence of a magnetic field. Under these conditions it would be expected that the magnetic lines of induction which passed through the specimens at the initial temperature would still link the specimen and in fact would now be even more firmly "frozen in," since any tendency for them to decrease would induce currents tending to preserve the status quo. Strangely enough, however, the experiment showed that in some mysterious way the lines of induction were automatically crowded out of the specimen and their presence in the surrounding space was made evident by the increased deflection of the ballistic galvanometer connected to the exploring coil. Fig. 1 shows the two forms of specimen used in the original experiment,[3] and the distortion of the initially uniform magnetic field which was found to exist when the specimens had been cooled well below the transition temperature. The most startling feature of this experiment is the fact that here apparently the mere

[3] Fig. 1 is reproduced from the paper by Meissner, Ochsenfeld and Heidenreich (20).

abstraction of degraded heat energy from the specimen enables it to do work against the magnetic field. Presumably the potential ability to do this work developed when the magnetic field was applied to the hot specimen and the cooling has merely removed an inhibiting effect. Nevertheless, the mere existence of the *Meissner effect*, as it has come to be called, indicates that the primary phenomena involved in the superconducting transition are inherently reversible in the thermodynamic sense.

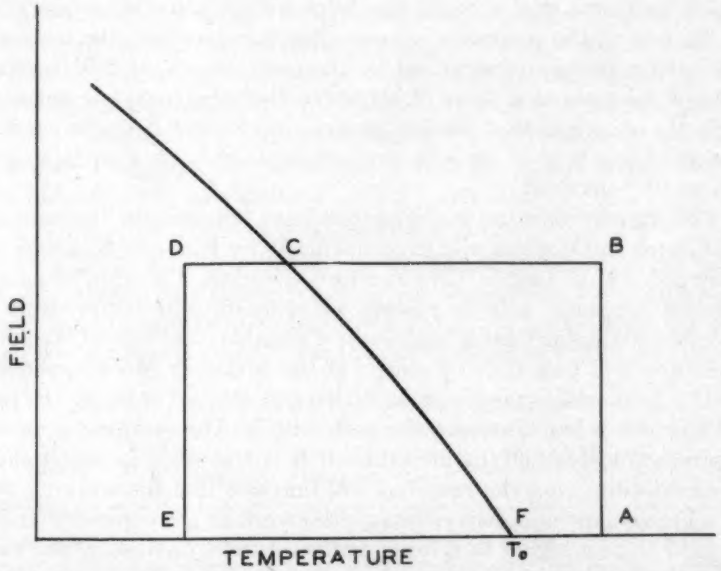

Fig. 2.—Curve FC is a graph of critical magnetic field H_k vs. temperature for a typical superconductor. Points to the left of this curve correspond to superconducting and points to the right, to normal resisting conditions.

The theorists have been prompt to recognize the implications of the Meissner effect and the older definition of a superconductor as a material in which inherently the resistivity equals zero has almost come to be replaced by the newer definition that the magnetic induction equals zero. Notable among the theorists are F. & H. London (15, 16, 17, 18, 19) who have developed a set of differential equations to describe a material in the superconducting state. The electrodynamic equation describing an ordinary conductor can be written

$$\rho J - E = 0$$

where ρ is resistivity, J is current density, and E electric force. In a superconductor $\rho = 0$ and $E = 0$, leaving J indeterminate. The Londons suggest as a fundamental equation

$$c \text{ curl } \Lambda J = -H$$

where c is the velocity of light, H the magnetic field and Λ a positive constant, characteristic of the material. Combining this equation with the usual equation c curl $E = -\dot{H}$ yields

$$c \text{ curl } (\Lambda \dot{J} - E) = 0$$

which indicates that any electric force will produce an acceleration of the flow of the system of superconducting electrons, the inertia of the system being characterized by the coefficient Λ. If this inertia is simply the mass of a cloud of otherwise free electrons, one per atom as in the calculations of Becker, Heller, and Sauter, it works out that the resulting flow of current is appreciable only in a surface layer about 10^{-5} cm thick.

The suggestion of reversibility has been followed up theoretically by Gorter and Casimir and experimentally by Keesom, Kok and van Laer (12, 14) at Leiden. Considering a diagram, Fig. 2, in which the applied magnetic field is plotted as ordinate and temperature as abscissa so that any point represents a possible condition of the specimen, you will note that by reason of the Meissner effect a specimen at D is in the same magnetic condition if it arrived there by the path AFED as if it had traversed the path ABCD. The complete rectangle represents a thermodynamic cycle. If it is traversed in the counterclockwise direction the material will function like the working fluid of a heat engine and deliver (magnetic) work at the expense of a flow of heat from a higher to a lower temperature. Conversely, clockwise cycles produce a refrigerating effect. Unfortunately this cooling is not well adapted to the actual production of low temperatures. The method of adiabatic demagnetization which has proved so very useful in the low temperature field in the last few years, while theoretically slightly analogous, is in detail totally different. A related consequence of this thermodynamic reasoning is that there must be a latent heat of transformation when by reason of the presence of a magnetic field the transition takes place at a temperature lower than normal. For Tl this latent heat at 1.91°K (0.45° below its normal transition) is 0.000346 cal/mol; and for Sn at 2.66°K (1.07° below its normal transition) is 0.0012 cal/mol. This theory would predict a magneto-caloric cooling when a thermally insulated specimen is carried from the superconducting to the normal state by an in-

crease in magnetic field. Such a cooling was found experimentally at Oxford by Mendelssohn and Moore.

A much more complete confirmation of the thermodynamic relations results from the calorimetric work at Leiden in which blocks of thallium and of tin were in effect carried around the cycle clockwise while the energy transfers were carefully measured. On calculating the various entropy changes and making due allowance for the magnetic work involved, the net failure to close the cycle, which could result from irreversibility, did not exceed 2 per cent of the gross change in entropy in the experiment with Tl and was even less in the case of Sn. In view of the exceedingly minute energies involved in these experiments, only 0.0004 cal/mol for thallium at 1.9°K, this agreement is a triumph of experimentation as well as of theory.

The transition may be regarded as at least analogous to what Ehrenfest has called a "change of phase of the second order" and on this basis Rutgers has deduced (27) the relation

$$\Delta C_p = (T_0/4\pi\delta)\ (\mathrm{d}H_k/\mathrm{d}T)^2$$

between ΔC_p, the discontinuity in the specific heat, and the slope $\mathrm{d}H_k/\mathrm{d}T$ of the transition curve. (δ is here the density and T_0 the transition temperature in the absence of a field.) This relation has also been verified experimentally for tin and thallium as shown in Table I.

TABLE I.—EXPERIMENTAL VERIFICATION OF RUTGERS' EQUATION

Element	T_0 (°K)	$\mathrm{d}H_k/\mathrm{d}T$ (oersteds/°K)	Δc(cal/°K/mol)	
			calc.	obs.
Tin	3.71	151	0.00229	0.0024
Thallium	2.36	137	0.00144	0.00148

The successes just enumerated may give the impression that the subject has now been fully explored, but when the Russian workers Schubnikow and Chotkewitsch, applying Rutgers formula to a PbBi alloy, which happens to have the very large value of 5000 oersteds/°K for $\mathrm{d}H_k/\mathrm{d}T$, they found no trace of any discontinuity in the specific heat although they could have detected as little as 1 percent of the predicted value. A similar negative result is reported by Mendelssohn and Moore for $PbTl_2$. Moreover, of the many repetitions and variations of the Meissner experiment which were promptly performed in other laboratories, only a few, such as those with very pure mercury, showed 100 percent Meissner effect, while others showed partial effects and some alloy samples showed no Meissner effect whatever,

but a complete "freezing in" of the induction. It is evident that there is more in the field of superconduction than is dreamed of in our present philosophy.

Next to the tremendous factor by which the conductivity changes, the most outstanding peculiarity of the superconducting transition is the abruptness of the change. One of the first questions which arises is therefore "How abrupt is the transition?" or in slightly different form "Does each volume element change abruptly or continuously through the transition?" In the usual polycrystalline wire specimens, the transition curve, in which the resistance is plotted against temperature or external magnetic field, has a finite slope and is rounded more or less at both ends, the range from 0.1 to 0.9 of the normal resistance being about 0.02°K. Curves obtained with monocrystalline specimens are notably steeper, sometimes having a range of only 0.0001°K, while those with alloys are often flatter. In certain mercury specimens subjected to a decreasing magnetic field the decrease in resistance has occurred in a relative few definite steps each presumably corresponding to the transition of an individual crystal. The increase of resistance was however continuous. This of course strongly suggests that in the ideal case the change is discontinuous. Most of the theoretical workers with due regard for Occam's warning against superfluous hypotheses, have assumed the discontinuous "all or nothing" basis, and have tried to account for the observed phenomena by suitable combinations within the test specimen of regions, each consisting of only one of the two fundamental states, superconducting or normal. Notable among these treatments are those of Gorter and Casimir and of the Londons. Recently Peierls (26) has abandoned this effort as impossible and postulates the existence of a third "transition state." In this state the resultant magnetic field H is required to have the constant value H_k but the magnetic induction B may have any value between 0 and H_k. For the (magnetic) cases which he treats, he is not concerned directly with the resistivity and so does not commit himself as to whether or not its variation is also continuous in the transition state. Experiments by Schoenberg (28) have been interpreted as suggesting that there is a finite resistivity in this intermediate state.

If the "all or nothing" hypothesis is to be retained (at least as regards the change in resistivity) we have as the next question, the cause of the finite range usually observed. The easiest answer in the case of polycrystalline wire would be that the individual crystallites having different orientation with respect to the direction of current

flow exhibited slightly different transition temperatures. Very careful work by de Haas, Voogd and Jonker on three monocrystals of tin having radically different orientation have shown only such exceedingly small differences in threshold temperature as to practically eliminate this explanation of the range. Mechanical strain is known to affect the transition temperature slightly and may well be the

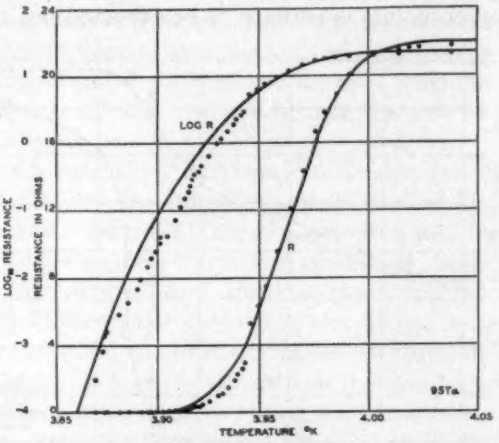

Fig. 3.—Transition curve of a tantalum specimen. Points show experimental values of resistance and of the logarithm of the resistance plotted against temperature. The curve R has the equation

$$R=\frac{R_n}{2}\left(1+\frac{2}{\sqrt{\pi}}\int_0^x e^{-x^2}dx\right)$$

where $x=3.09\ (T-3.963)$ and T is the temperature and R_n the normal resistance.

cause of at least part of the observed range, the rest is still unexplained.

A supplementary question is "How far does the toe of the transition curve extend?" The importance of this lower end of the curve lies in the fact that the rate of decay of any induced currents is fixed by the residual resistance, and true superconducting behavior is to be expected only when the resistance is so low that the relaxation time of the currents is long compared with the duration of the experiment.

One example of a transition curve obtained at the National Bureau of Standards by Brickwedde, Scott and the author is shown in Fig. 3. This is for a specimen of hard-drawn tantalum wire, 0.075 mm in diameter, 210 cm long, as measured at decreasing temperature with a

measuring current of 1 ma. The S-shaped distribution of the observed points rather suggested that the influences tending to shift the transition temperatures of the various parts of the specimen away from the mean might have a random distribution. To test this, the solid curves were calculated from the assumed Gaussian distribution passing through the mid-point R and having a parameter h fitted to the slope of the curve at that point. The good fit of the resistance curve R to the observed points is perhaps to be expected but the fact that

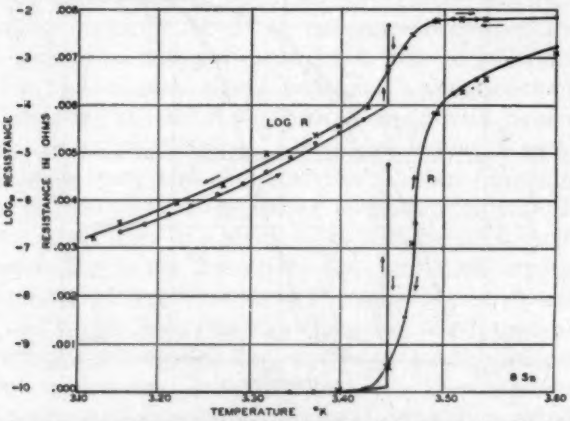

Fig. 4.—Transition curve of a tin specimen. Experimental values of resistance plotted against temperature.

the left-hand extremity of the log R curve fits so closely the observations at values of resistance only one ten-thousandth of that for which the curves were fitted is striking and perhaps significant.

Another transition is shown in Fig. 4. This is for a sample of extruded tin wire 0.22 mm in diameter measured with a relatively large current, viz. 1.8 amperes. The bulk of the transition is similar in trend to the preceding, though it cannot be so closely fitted by a simple Gaussian curve. The "toe" of the curve is however totally different and shows a prolonged almost exponential variation with temperature which is suggestive of a Boltzmann distribution.

The preceding examples have shown transitions as the temperature was varied at a constant (zero) magnetic field. With polycrystalline specimens, the curves obtained on varying the magnetic field at constant temperature are much the same in shape and are nearly the same whether the field is parallel or transverse to the direction of current flow.

De Haas, Voogd and Jonker have found that if a cylindrical single crystal is subjected to a transverse magnetic field a markedly different type of transition is obtained. The field required for full resistance is about double that at which a measurable resistance is first noted, the resistance rising almost linearly with the field provided the current is fairly large. With smaller currents the resistance at intermediate fields is materially less than with larger currents. The wide range of field over which the transition extends obviously calls for a different type of explanation and some recent work on the details of the process of the penetration of a magnetic field into a superconducting body may perhaps furnish the clue to the origin of curves of this type.

The work in question, by de Haas and Guinau (10, 11) at Leiden on a monocrystalline tin sphere, parallels and amplifies work by Mendelssohn and Babbitt (21, 22, 23) at Oxford and by Schoenberg (28) at Cambridge on polycrystalline specimens. Starting with the sphere at a low temperature, these workers applied an external magnetic field which in the absence of the sphere would have been uniform, and measured the intensity of the resulting field at various points near the equator of the sphere and in holes bored through it. The intensity was measured by noting the change in resistance of small bismuth wires suitably placed. If H_k is the critical value of magnetic field for the particular temperature at which the sphere was held, then for external fields less than $2/3\ H_k$ the sphere behaved as if it had zero permeability and all the lines of force were forced to detour around it. It follows from the equations of the electromagnetic field that under these conditions the field intensity at the equator is $3/2\ H_0$ when H_0 is the intensity of the external field at a great distance (or the intensity which would exist at the center if the specimen were absent). Measurements confined to external points cannot determine whether such a field distribution is the result of a true diamagnetism existing throughout the body of the sphere (its volume susceptibility being $\kappa = -1/4\pi$), perhaps as a result of microscopic Amperian currents, or whether there is a macroscopic system of currents circulating around the surface of the sphere in planes normal to the axis of the field. The measurements at Leiden using bismuth detectors located in a hole along the polar axis, and in a thin equatorial crevasse could make the necessary distinction. The detectors showed zero magnetic field under these conditions, and thus proved that the second hypothesis (viz. macroscopic currents circulating in the surface of the sphere) was the correct one.

The next question is "What will happen when the field is increased so that $3/2\ H_0$ exceeds H_k?" It might well be supposed that the material in an equatorial zone would become resisting so that the macroscopic currents there would die out, but that a new system would develop within the material so that the central portion in the form of a prolate ellipsoid would still remain superconducting, and that currents on the surface of this inner region would separate it from the outer resisting zone. It is to be noted that if such a distribution existed the field would drop off rather rapidly outside it so that the outer equatorial zone would again be in a field less than H_k. There is a little evidence in the Leiden data that this condition may exist over a narrow range, but when H_0 has increased by 10 percent above $2/3\ H_k$, the entire system of macroscopic currents on the spherical surface seems to break down. The data yielded by the internal detectors then become consistent with a truly diamagnetic body. The system of persistent currents must therefore have become subdivided into eddies smaller in diameter than the detector. Perhaps these enclose "columns" or "needles" of superconducting material, the axes of which lie parallel to the field, but they may of course degenerate in both dimensions into small spherical volumes of perhaps molecular dimensions. The total flux of induction threading the equator of the sphere increases linearly with further increases in the external field until, when this has reached the value H_k, the specimen behaves like a normal material in which $\mu = 1$ or $\kappa = 0$. For values of H_0 intermediate between $2/3\ H_k$ and H_k the field distribution inside and outside is that corresponding to a material having a mean permeability given by the relation: $\mu = (3H_0/H_k - 2)$. The detailed nature of these current eddies which must persist and enclose certain superconducting and fluxless regions embedded in a matrix of normally resisting material, still remains to be studied.

The picture suggested by these experiments on spheres can now be carried over to the cylindrical wires previously discussed. For a circular superconducting cylinder placed transversely in the field, the factor by which the initially uniform external transverse field H_0 must be multiplied to get the maximum intensity is 2, instead of 1.5 as in the spherical case. Von Laue pointed out that the first signs of disturbance noted by de Haas and Voogd and Jonker occurred at about 1/2 of the field which was found to be critical in the longitudinal case, and offered this distortion of the field by a factor of 2 as an explanation. If the penetration had occurred by the gradual process first suggested above, so that the superconducting region became

an elliptical cylinder of gradually increasing eccentricity, the long axis of the ellipse forming the diameter of the wire parallel to the field, von Laue's explanation would fail, because the superconduction along this axial "blade" would be ample to prevent the appearance of resistance. However, since the penetration of the sphere is not continuous but proceeds by an abrupt degeneration of the system of persistent currents into small regions having their axes parallel to the field, the surrounding matrix of normally resisting material may well form a continuous "phase" and introduce a measurable resistance even when most of the total volume is still in the superconducting state. If the total induction increases linearly in the cylindrical as well as in the spherical case, as seems very reasonable, the fraction of the total volume which is normally resisting will also increase linearly (assuming $B=0$ in the superconducting portions) and the resistance offered to the measuring current which flows in a direction transverse to this columnar distribution would also be expected to vary linearly. To explain the other features of the results of de Haas, Voogd and Jonker we need only make the further assumption that imperfections in the crystal or some other causes have produced a few slender superconducting paths running more or less axially from one main superconducting column to the next. In the intermediate stage a very small measuring current can meander mainly by such paths from one end of the wire to the other with but little resistance. A larger current, however, attempting a slender path, will produce such an intense local magnetic field around itself as to destroy the superconductivity of the path and will consequently experience the normal resistance except when flowing athwart the larger superconducting columns.[4]

The fact that a measurable resistance just appears at a field somewhat greater (by about 15 percent) than that predicted by von Laue can be explained by assuming that the initial stages of penetration proceed some distance by the gradual process just suggested before the degeneration of the persistent current system sets in.

A phenomenon which is apparently distinct but which may perhaps be merely another manifestation of this same degeneration of the current system when a magnetic field penetrates a superconductor was discovered by Brickwedde, Scott and myself at the National Bureau of Standards in 1934. It can best be described by following

[4] It would appear that the curious result, deduced by Peierls for material in his "transition state," that the boundaries of the superconducting regions must be (generalized) cylinders parallel to the external field will also apply in this case and thus insures the needed parallelism of the superconducting columns.

the course of an experiment in which the apparent resistance of a specimen of wire carrying a relatively large current is watched as the temperature is raised gradually from a low value through the transition range. Fig. 4 shows a typical example of this phenomenon in a tin wire. At a particular temperature, in this case 3.44°K, the resistance increases spontaneously in the course of a few seconds to 0.0048 ohm, a very considerable fraction of its full value, and then decreases again at a somewhat slower rate to a fairly low value 0.0006 ohm. Further increase in temperature causes the resistance to rise again along a curve which approximates the normal transition. No corresponding phenomenon is found on cooling. For lack of a better term we have called each of these spontaneous increases of resistance followed by a decrease an *overshoot*.

I have described this overshoot as occurring as the temperature is raised with a constant current in the wire and a constant external magnetic field. Similar overshoots occur when the current is increased at constant temperature and field and when the field is increased at constant temperature and current. They are much less marked when they occur at small currents, as is the case when temperature or field is high, than when they occur with a larger current at a lower temperature.

After an overshoot has proceeded to completion, a prompt repetition of the stimulus which produced it, as by opening the circuit and reclosing it with the same large current, will *not* produce a second overshoot. Hence, although its resistance is again very low, the specimen just after the overshoot must be in a condition different from that just before the overshoot. The original condition in which the possibility of an overshoot is again latent can be attained by cooling the specimen a few tenths of a degree for a few minutes.

To relapse again to speculation, may it not be that the resistance during the overshoot exists while the regime of current flow is changing from a simple macroscopic distribution, stable at low temperatures and induced perhaps by the Meissner effect, to a new regime characterized by a subdivision of the volume into regions some of which are resisting while others are superconducting? This second regime may utilize more effectively than the first those portions of the interior of the specimen which happen to be particularly favorably situated to be superconducting.

The classic experiment of Meissner and Ochsenfeld, itself, demonstrates that, on cooling their tin cylinders while they were carrying a current, there occurred a spontaneous change in regime of current

flow which was the converse of the change which we are now postulating to explain the overshoot.

One peculiar feature of this overshoot phenomenon is the fact that it involves a process which requires a certain time for its completion. The time rate of progress of a process often gives a valuable clue to the nature of the process. It was with this in mind that the workers at Toronto undertook a study of the behavior of superconductors at high (radio) frequencies. At first McLennan thought he had found a real effect but later it was concluded that the observed effects had resulted from changes in the magnitude of the currents used and that there is no appreciable change in the transition point up to frequencies of 3×10^7 cycles per second.

Two years ago I had the honor of presenting to this Society a report of somewhat similar experiments by Brickwedde, Scott and myself which however went one step further and showed that a tin wire could change from the superconducting to the normal state and back again fast enough to keep in step with the pulsations of an impressed magnetic field which had a frequency of 3×10^6 cycles per second.

More recently Keesom and van Laer (13) have announced that when an ellipsoidal tin specimen passes from the superconducting to the normal state as a result of increasing temperature, in the presence of a constant magnetic field, there is a time lag of the order of 30 seconds. This lag in the transition is made manifest by the corresponding lag in the evolution of the latent heat. No such lag is observed when the transition is stimulated by an increase in magnetic field at substantially constant temperature. If a superconducting tin cylinder of the diameter (3.5 cm) used by Keesom and van Laer had suddenly been endowed with the full normal resistance appropriate to 4°K, the lag in penetration of the magnetic field which would be expected from the induced eddy currents comes out at only about 1.5 seconds, and any smaller eddy circuits in normally resisting material would respond still more quickly. If the lag is the result of the time required for eddy currents to die out, it is evident that the average resistivity of the circuits must be much less than normal and that at least 95 percent of the circuit must be superconducting. The time required for an *overshoot* is of the same order of magnitude as the thermal lags reported from Leiden, but the stepwise changes noted during the decrease in resistance imply that the phenomenon may be more complex than a mere eddy current decay. Both Mendelssohn and Pontius (24), and the Russian workers have also reported similar

changes in magnetic induction with time, the former noting step-like changes. Keesom and van Laer suggest that this lag is an indication of a weak coupling between the atomic lattice and the system of superconducting electrons, while the prompt response to changes in magnetic field indicates in contrast to this, a strong coupling between this field and the superconducting electrons.

The Russian workers Rjabinin and Schubnikow (29, 30) have attacked the subject from the point of view of the magnetician and using as a specimen a fairly long cylinder (or prolate ellipsoid) have obtained B–H curves both for Pb and for $PbTl_2$. With a specimen of this shape the distortion of the external field by the specimen is much less than with a sphere, and the corrections for the "demagnetizing effect" of the ends is much less. Of course in this topsy-turvy subject, the "demagnetizing" action of these apparently diamagnetic specimens really aids the external field. The measurements on the Pb specimen showed that as the applied field is increased from zero the flux varies as would be expected theoretically, being zero up to the critical field and then rising abruptly to the value corresponding to $\mu = 1$. When the field is reduced below the critical value a partial Meissner effect is observed, the flux decreasing abruptly but not to zero. Further decrease in the applied field causes a further decrease in flux (i.e. some flux was neither "frozen in" nor expelled by Meissner action). There is a positive remanent flux when $H = 0$, and as H is increased in the opposite direction this flux continues to decrease linearly until it has reached zero just as H reaches the value $-H_k$. The remainder of a cycle yields a symmetrical and reproducible hysteresis loop.

When the Russian workers performed a similar experiment with an alloy $PbTl_2$ the dictum of McLennan was again exemplified. They found to their surprise that the magnetic field began to penetrate the specimen at a field H_{k1} much less than that value H_{k2} which previous experiments had shown to be critical as regards the restoration of resistance. The penetration was however not quite complete and the flux within the specimen slowly proceeded to approach more and more closely that corresponding to $\mu = 1$, finally reaching that value at the field H_{k2} some 17 times that at which penetration began.

On reducing the field a slight hysteresis was observed and at zero applied field there was a small but definite remanent induction. Qualitatively similar results were obtained on a PbBi alloy and have been confirmed by other workers. Moreover it is found that with alloys the critical value of current which destroys the superconduction is less even than that which would produce the penetrating field

H_{k1} and hence much less than H_{k2}. I have already mentioned that these alloys violate Rutgers' relation for the specific heat. It therefore seems that we must subdivide the general class of superconductors into two sub-classes for which the provisional names of *normal* and *anomalous* have been proposed by the workers at Toronto. A superconductor may be classed as normal if

1) it shows no penetration by magnetic fields less than that required to restore resistance to even small currents;
2) the Meissner expulsion of flux on cooling is manifested to at least some extent under favorable conditions;
3) the restoration of resistance by heavy currents coincides with the attainment of the critical field at the surface in accordance with Silsbee's hypothesis;
4) the change in specific heat at the transition is related to the critical magnetic field by Rutgers' equation.

While all of these properties have not been checked in all cases it seems probable that tin, lead, thallium, and mercury are normal in all these respects. On the other hand, a substance which disobeys one of these rules is classed in the anomalous group. In this anomalous group are now listed the element Ta and the metallic compounds $PbTl_2$, Bi_5Tl_3, Pb_2Bi, and PbSn. All of them have not been tested for all of the properties listed but none has been found to be exceptional in one respect and normal in another, so that it seems probable that they will be found to be anomalous in all respects.

It is perhaps therefore not too wild a speculation to suggest that it is the critical field H_{k1} for penetration which is to be taken as the basis not only for property (1) but also for use in Rutgers' equation and in estimating the critical currents. The primary distinction of the anomalous group would then become merely the single property of being able to carry without resistance a small test current in a longitudinal direction in a field up to H_{k2} much larger than H_{k1}. Unfortunately the jumps in specific heat calculated from the H_{k1} values are so low as not to be measurable. It should however be possible to detect experimentally a correlation between the Meissner expulsion and the penetrating field if one exists.

The correlation between the critical current and the penetrating field for anomalous materials is definitely not as close as in the case of the normal materials. Yet even here when the critical currents for wires of different diameter are compared it is found that it is the tangential magnetic fields produced by the critical currents which are equal and not the currents themselves nor the current density. The

observed difference in the penetrating powers of magnetic fields produced by internal and by external currents remains a challenge to the future.

The workers at Toronto (25) have made a very extensive study of the behavior of thin films (0.5μ to 30μ thick) of Pb and particularly of Sn. For convenience these films are supported on wires or tubes of constantan or of German-silver on which they are deposited either by dipping in the molten metal or electrolytically. They find that films less than 1μ thick do not become superconducting at any temperature down to 2°K and that if an outer layer of copper or nickel is deposited over the tin no superconduction appears unless the film is at least 4μ thick.

The films of tin behave very much like alloys of the anomalous class, and have abnormally high critical fields and abnormally low penetrating fields and critical currents. The abnormality increases as the film becomes thinner. The curves showing the progressive penetration of magnetic field in these tin films are strikingly like the corresponding curve for $PbTl_2$ observed by the Russian workers.

This connection between superconduction and a physical dimension (i.e. thickness) should prove a valuable clue to some scientific detective. In fact certain theoretical calculations of Becker, Heller and Sauter have been applied by Grayson-Smith to indicate that a necessary thickness of the same order of magnitude as that of the films used might be expected purely from the effect of the mass of the electrons in retarding their otherwise "free" response to an electric field.

You will have noted that throughout this discussion it is the magnetic field which has been considered the limiting variable which could not be exceeded without causing a breakdown of the superconducting mechanism. Yet even here we have a paradox, for while the material is superconducting, the field cannot penetrate it, and if the field cannot exist in the material how can it interfere with its ability to conduct electricity? Of course the answer is that the field is kept out by a flow of current and hence that the permissible linear density of current expressible in amperes per centimeter width along the surface is really the limiting feature. It would seem much more reasonable to expect that a surface density of current expressible in amperes per square centimeter of cross-section would constitute the more fundamental limit. Perhaps this work on films may complete the picture by showing an independent reason why the superconduction current is limited in its possible thickness.

I have reported tonight the current tidings from the many expeditions in this field, both from the amateur dashes of the Washington group up the most readily accessible peaks and points of vantage as well as from the larger and more completely equipped expeditions guided by the years of experience of Leiden. The expeditions have sent back pictures which show beautiful agreements between thermal and magnetic measurements and between theory and experiment and yet other pictures of yawning chasms between quantities which would be expected to agree, and of precipitous discontinuities in what would be expected to be a continuous declivity. Let us hope that ultimately the surveys will close, and that from some of the higher peaks in this region we may secure more penetrating vision than ever before into the innermost nature of electricity and of matter.

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BOTANY.—*A basis for mycogeography*[1]

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Where ships unload strange cargoes from distant ports even the loiterer has a quickened feeling of romantic curiosity about those cargoes. Perhaps the herbarium botanist may be excused for a quickened pulse when he examines specimens from foreign lands or even from distant sections of his own land. Frequently the specimens are novelties that cannot be matched in our collections; again, however, the specimens from the antipodes are identifiable as species to be found also in our own dooryards. That is not true of most seed plants. One can readily detect an ordered arrangement, a seeming causal relation between geography and the distribution of vascular plants. But all too often our sense of order is outraged by the apparent contradictions afforded by our incomplete knowledge of mycogeography. As Bisby (1) has pointed out, "Mycologists have been able to map

[1] Address of the retiring President of the Botanical Society of Washington, presented December 3, 1935. Received February 20, 1937.

with accuracy the geographic distribution of comparatively few fungi." On the other hand, phanerogamic botanists have been able not only to map with approximate accuracy the distribution of seed plants, but to formulate principles governing their distribution. In spite of a paucity of such attempts to generalize regarding the geographic distribution of fungi, some phases of this many sided subject will be discussed, avoiding in so far as possible questions concerning their dissemination.

EDAPHIC FACTORS

In the experience of those who have attempted to cultivate a fungus the most immediate problem is to determine its nutrient requirements or what the plant geographer and the ecologist would term the "edaphic factors." As nutrients all fungi require the elaborated organic materials of plant or animal origin. Certain fungi if not especially *choosy* in this regard may have a wide distribution over the earth and are said to be cosmopolitan in range. This is true of the Myxomycetes, most species of this taxonomically questionable group being found indiscriminately in the Arctic as well as in the tropics. Lichens do show obvious relations to climate, but they present problems of their own and are not discussed here.

Aquatic fungi.—The sea is of much greater area than the land, but, unfortunately, even less is known about the fungi in the sea than about those in fresh water, and much less of fresh water fungi than of those to be found on the land. Even so, in the case of the true water molds we have the conformity of a taxonomic group to aquatic habitats, although within the water itself the fungi may have highly restricted sources of nutrition, that is to say, the tissues of particular species of plants or animals. Despite all the effort that has gone into the study of water fungi very little is on record about those growing upon algae, in fact, more is known about the fungus parasites of fungi than about those of algae, both terrestrial and marine. To a certain extent water molds appear to be cosmopolitan and European species, or species closely related, are frequent on this continent. Of late years studies of water molds upon protozoa and lower invertebrates have revived an interest in such fungi, but thus far little is known of their geographic relations. More perhaps has been known about those few described species, chiefly cosmopolitan, which grow upon fishes.

We would expect marine fungi to be cosmopolitan. A striking recent instance was that of an apparently unknown ascomycete grow-

ing upon eelgrass (*Zostera*), along the eastern coast of Canada. It was described as new in 1934 (5), and within the same year it was reported by Tutin (11) from England, and by Petersen (6) from Denmark. A similar cosmopolitanism has been observed for *Tetramyxa parasitica* which grows in both hemispheres upon *Ruppia maritima*, another salt-water seed plant. We know of these instances because they have been conspicuous upon particular seed plants, and because economic interest has focused considerable attention upon them. Doubtless numerous analogous cases exist, but have not been studied and recorded.

Terrestrial fungi.—During the last 150 years there has accumulated a vast literature concerning fungi that have been found in the earth or growing upon plants and animals or their remains upon the earth. There are numerous fungus floras of various nations, states or other areas, usually mere lists with new species added where the author was unable readily to identify certain specimens. One can peruse such lists *ad nauseam*, but unless the specimens on which they are based can be examined for verification the particular names in these lists are too often of doubtful meaning. For the most part these floras and the many related records of specific occurrences do not present any easy road to an understanding of the geographic distribution of fungi. When, however, these seemingly unrelated accounts are carefully sifted, verified and pieced together into a new pattern they may present a picture with some significance for the plant geographer.

Regional lists of the more common sort include, of course, many of the conspicuous mushroom fungi, which grow to a large extent from the earth or from partly buried materials. These records are of greater meaning, however, when supplemented by the more technical studies of the type undertaken by the soil microbiologist. Although such studies are not directly concerned with geography they have afforded means of explaining significant differences between soil floras.

Since most soils are surcharged seasonally with water, the soil is itself a harbor for some aquatic fungi; and certain studies of water molds in soils have been illuminating, but they are insufficient to indicate broad geographic relations. Water molds in soils must suffer periodic drouth and during dry seasons only those can survive which are capable through resistant spores or other means of enduring the drouth conditions.

Many fungi thought of as soil fungi in reality grow from roots or other remains of organic life underground. When restricted to particular host species the fungus involved cannot be cosmopolitan, but is

limited to the region where that host exists. Perhaps such a fungus is not properly a soil organism anyway. In general it is not improbable that soil fungus floras are as much determined by the peculiarities of the decomposition products of certain plant and animal remains as by the character of the inorganic substances present.

That the chemical nature of a soil, or for that matter of any natural medium, is a significant factor in determining the success of a fungus is attested by the results of a multitude of studies of the growth of various species *in vitro* correlated with studies of them in their natural habitats. One of the most readily observed chemical effects upon a fungus is that produced by the reaction of the medium. Such effects were recognized and measured even before the present conception of hydrogen-ion concentration was given publicity. As an instance may be cited the writer's attempt in 1915 to isolate on artificial media the purple *Rhizoctonia* from alfalfa roots. Other fungi and bacteria grew as well or better than the *Rhizoctonia*. Slight acidification prevented growth of bacteria and most contaminating fungi, but there was a contaminating *Fusarium* which was almost as stubbornly tolerant of acid as the *Rhizoctonia*. It was found, however, that with the continued addition of acid a point was reached where the *Rhizoctonia* could tolerate the acid and grow while the *Fusarium* could not. The reaction of the medium here was plainly a factor in regulating the fungus flora. Many comparable studies could be cited wherein the reaction determined the ability of a fungus spore to germinate and of the mycellium to grow or to produce reproductive bodies. The common cultivated mushroom is an excellent example. According to some unpublished data furnished by Dr. E. B. Lambert, *Agaricus campestris* has a considerable latitude in regard to acid tolerance for vegetative growth, but it will produce fruiting bodies only if the casing soil is above pH5. Those who have gathered mushrooms of this species by the bushel in such neutral or limestone soils as occur in the Ohio Valley have always remarked upon the contrast afforded by the poor harvests to be encountered in the acid soils along the Atlantic seaboard. The same is true with respect to the relative abundance of morels in their season in limestone areas as contrasted with their scarcity here. Morels have been noted by various observers as especially abundant following fires in forest and field. W. H. Long (4) in a discussion of fungi about Austin, Texas, called attention to their size and abundance in alkaline cedar-brake soils. Other effects of certain soil constituents have been observed. It is known that some minerals when in sufficient quantity are toxic to certain fungi

and others are stimulating, but our knowledge of a consistent relation between soil minerals and mycogeography is sadly insufficient for any generalization.

That complex biological relations other than saprophytism and parasitism exist between fungi is apparent from studies in the laboratory. It is a common observation attested by numerous records that certain fungi in mixed culture thrive together while others are antagonistic to each other. Studies of successions such as those on dung long ago suggested the production by some species of substances toxic or deleterious to certain others, or to themselves, yet not deleterious at all to certain species. Such ecological relations are detected in artificial cultures and have been noted for localized natural areas in studies of fairy-rings, but we have no knowledge of their effect over any extensive range.

The physical condition of a soil, whether sandy or clayey, is an obvious determinant of some species. Certain species are rarely met except in sandy soils, but here again the question of distribution is locally ecological rather than geographic. If the nomenclature of fungi were a clue to specialization in sand, such specialization is rare for few fungi bear the specific names *arenarius*, *arenicola*, etc., which appear rather frequently for seed plants.

It is true that many fungi in soils are more or less specialized in their saprophytism or parasitism. But published accounts with respect to substrata have at least a shadow of accuracy when the record gives the name of the plant, living or dead, as the natural medium for the fungus. The degree of accuracy becomes greater for those substrata not buried in the soil. A glance at any of the regional lists, or better into Saccardo's *Sylloge Fungorum*, reveals an overwhelming number of fungi recorded as growing upon the tissues of particular host plants, chiefly the aerial parts of such plants. It is evident that for ages past there has been a specialization of certain species either as saprophytes limited to specific organic substrata or as parasites varying in behavior through specialized facultative parasitism to obligate parasitism.

Fungi specialized to grow on animals.—There are indications that some fungi may be versatile enough to grow upon non-living tissues of both plants and animals. But there is a large number of species of fungi specialized to grow only upon or in certain animals. Too little is known, unfortunately, about the nature of their structure or activities. That the field is unexplored is indicated by the fact that Seymour's Host index of fungi of North America (8), considered

practically complete up to 1923, devotes but 20 out of a total of 718 pages to names of fungi known upon animals, the rest (679 pages) listing the names of fungi recorded upon plants. Of the 20 pages listing fungi on animals less than one page includes all those fungi then known to grow upon the lower invertebrates in America. Less than one page is devoted to fungi on vertebrates. The lion's share of the 19 pages of zoöphilous fungi consists of those on Arthropods, and here but one fungus is recorded for the Crustacea. The 19 pages of fungi on Arthropods is practically an index of the species of Entomophthorales and Laboulbeniales on insects described by the late Roland Thaxter. Although he revealed a new world of fungi we are still without an adequate knowledge of their geographic distribution. That this small total of fungi on animals is not a true picture of the condition in nature is attested by such an increased interest in the subject since 1923 that there have been more American records of such fungi since 1923 than before. Not only in America but in Europe also there is an increased activity in studies of fungi upon animals, although we are still without knowledge of their distribution over the earth except in so far as they are obviously related to disease in man. The geography of certain fungous parasites of man is better known because there is a wealth of clinical record of thrush, of ringworm, and of certain even more repulsive skin diseases caused by fungi. Many of these are almost exclusively tropical while others are known only in temperate climates. Whether the prevalence in the tropics of certain of these fungi is due to the climate or to the less sanitary habits of many tropical peoples is an open question. Certain it is that there is here a distribution according to geography. There is a preponderance of Italian records of fungi pathogenic to man, but this disproportion is doubtless merely the result of the mycological training and traditional interest in mycology in Italy.

CLIMATIC FACTORS

This distribution of fungi in man suggests a response to climate because *Homo sapiens* of various races tends to be susceptible to the fungi of a given region. Many fungi both saprophytes and parasites of plants are limited to the tropical or neo-tropical zone, although certain species of the *Xylariaceae*, and certain Phalloids show notable extensions northward. These latter saprophytes occur sparingly along our seaboard, but their main range is from the West Indies to Brazil. Species of *Balansia*, obligate parasites of grasses, have this same range. When plants infected by some species of *Balansia* are culti-

vated under cool conditions, the fungus grows more slowly or dies while the host, continuing to grow, becomes normal, i.e. without the fungus. This temperature effect on the host and parasite is related to a climatic effect upon their geographic distribution. Where substrata or hosts are limited to the tropics it is easy to suggest that the ecology of the host is the chief factor in limiting the fungus to the tropics. Such is doubtless true of the unique genus *Camillea* with remarkable species that stand out from the woody substratum, resembling nothing so much as nails partly driven into the wood. Species of *Camillea* are always tropical and it is thought that their substrata are woods limited to the tropics. Many species of autoecious rusts are limited to particular portions of their normal host ranges. In this region we have a species of *Pucciniastrum*, *P. americanum*, growing on red raspberries. This species is found northward into the Canadian zone, but in that life zone it meets a close relative, *P. arcticum* which is found through the Hudsonian and Arctic-alpine zones into Asia. The remarkable rust genus *Ravenelia*, largely tropical, ranges into the United States, and the species are generally more southern than most of the hosts. The powdery mildews are much more in evidence in the drier western United States than eastward, but when we have arid conditions eastward they become more prevalent here. This is really not so much plant geography as it is epidemiology; but it does illustrate a climatic effect upon normal occurrence. *Puccinia glumarum* causing stripe rust of wheat is practically restricted to the western highlands and the Pacific Coast from Mexico into Canada. This distribution is in marked contrast to that of most common parasites of wheat; and the role of temperature and prevailing winds as pointed out by Sanford and Broadfoot (7) is here a factor in the general climatic complex affecting varying annual dissemination.

Although rusts and many other types of fungi are able to thrive in comparatively arid as well as moist regions because they utilize moist conditions when they appear, most of the Phycomycetes are not so versatile. Tucker (10) has noted that species of *Phytophthora* are favored by high humidity and are rare in arid regions. He notes that certain species are primarily tropical in distribution while others are limited to temperate regions. In contrast to the Phycomycetes there are doubtless many fungi, which like the Texas root rot fungus, *Phymatotrichum omnivorum*, are found only in the arid Southwest. The most comprehensive and significant regional lists of fungi have been compiled for arctic areas. These lists, chiefly of parasitic fungi,

contain a great number of species well known to the European and North American mycoflora. But a considerable number of species in the Arctic (common to alpine areas also) do not otherwise occur in Europe. This has been ably discussed by Lind (3) who concluded that compared with the condition in temperate regions Pyrenomycetes were numerous, Discomycetes few, powdery mildews rare (some developing no conidia, others only conidia), that the Uredinales were largely those having a perennial mycelium without a full complement of spore forms, and as expected certain Peronosporales were abundant. Lind noted also that there were few saprophytic molds and bacteria to compete with other saprophytic fungi in plant tissues. The well-known parasite of the rusts, *Darluca filum* (Biv.) Cast., was common in the arctic as well as in temperate and tropical areas. The arctic mycoflora thus includes temperate-zone and cosmopolitan species as well as numerous endemics.

Most instances of altitudinal distribution of fungi appear to be merely responses to the requirements of temperature and humidity which delimit the so-called 'life zones.' An instance of a different sort is that of an old claim recently reiterated by Costantin (2) that rust on coffee, disastrous at low altitudes, becomes rare at certain higher elevations at which the coffee can still thrive. Here in the eastern United States, the apple-scab fungus is more abundant at higher elevations, but it is primarily northern and the apple bitter-rot fungus southern. The former is chiefly restricted to the Canadian and Alleghanian life zones and the bitter rot organism chiefly Carolinian and Austro-riparian. But there is an annual fluctuation of range depending upon seasonal conditions. The rapid adaptation of some fungi enables them to surmount the barriers which for seed plants permit more easy delineation of life zones.

BARRIERS AND ENDEMISM

These seasonal fluctuations in apparent range for fungi restricted by temperature demonstrate the effectiveness of unfavorable temperatures as barriers. A temperature barrier is as effective as an ocean. With the unintentional aid of modern man those obvious barriers of temperature and of ocean tend to be circumvented. All are familiar with the remarkable adaptation of the Andean potato to the climate of Ireland with its fulfillment of the need in Ireland for a cheap and suitable source of food, and with the fact that the first Irish potato famine came on shortly after the early steamboats with more rapid transportation could have carried the potato blight

fungus alive to Ireland. Here the shorter journey enabled the fungus to survive the tropical voyage, an impossibility in the slower sailing vessels. In like manner, the chestnut-blight fungus, endemic in Asia, by the aid of man was enabled to surmount the ocean barrier.

The penetrating and almost nauseating odor of the Phalloids or stink-horns is familiar to all. In New Zealand, Australia and South Asia there are certain remarkable species of these found nowhere else. One of these known as *Lysurus mokusin* is endemic in south China, but on a steaming hot midsummer day it can be found emerging from the ground in the court back of the Smithsonian Building and at several other points in Washington. Washington, D. C., and Chico, California, are the only places known for it other than South China. Our eastern American Phalloid, *Dictyophora duplicata*, is now established in Germany and Austria as has been reported by Ulbrich (12). It is possible, indeed likely, that the common mushroom, *Agaricus campestris*, which grows primarily on horse manure, came to America with the horse.

Other barriers, of course, are mountains and deserts and the absence of favorable substrata and hosts. It is obvious that those fungi requiring special hosts may be found wherever those hosts exist. An excellent example is afforded by that remarkable ascomycetous genus *Cyttaria* parasitic only upon species of *Nothofagus*, the antarctic beech, with the coincident discontinuous geographic distribution in Chile, New Zealand, and Tasmania. It is conceivable, however, that where a plant occurs sparingly its obligate parasite may not be able to reach all of its outlying stations, especially if the fungus spores are not windborne. Such a case was reported in 1917 by N. E. Stevens (9) for the natural distribution of *Endothia gyrosa* on oaks. He found that in the northern United States where oaks became infrequent the fungus, although apparently able to survive and reproduce itself under existing conditions, was much less frequent than the host. In other words there was here insufficient opportunity for infection, an actual barrier of non-oak trees existing between infected trees and uninfected trees over which barrier the fungus could not spread.

In the same manner the absence of a requisite alternate host from a given area would preclude the reproduction within that area of any fungus requiring two different host species for the annual cycle. Such is the condition in the genus *Gymnosporangium* (our common species in this area forming galls on red cedar and the alternate stage on the apple and its close relatives). Changes in the natural range of species have been much influenced, firstly by the introduction through cul-

tivation of different hosts and substrata and secondly by the local eradication of certain hosts and substrata. That the directions of unfavorable winds complicated, of course, by bird migration, can prove barriers, was shown by the slow westward spread of the chestnut-blight contrasted with its rapid spread southward.

The presence of deleterious organisms, parasitic, predaceous or merely chemically antagonistic to the growth of a particular fungus, ought to constitute a barrier, but consistent evidence is lacking.

Many endemics still persist in their localized habitats never having been gathered elsewhere. Endemics may present practical problems, as, for example, where some such fungus has surmounted its natural barriers to assume economic importance in the newly invaded region. Thus it will be seen that the natural distribution of a fungus species is significant in interpreting its possibilities in a new range. Through the agency of transported plants and animals as direct vectors man has been the agent in notable changes from endemism to cosmopolitanism.

In eastern America we have many species extending from South America up the eastern coast of the United States. Certain species of *Xylaria*, *Hypoxylon*, *Simblum*, *Clathrus*, as saprophytes, and of *Balansia* and *Dothichloe* as parasites show this range. They are not found west of the Cordilleran backbone. No species of *Balansia* and *Dothichloe* occur on the Pacific Coast of America, although their susceptible hosts are present. Cases of this sort, actually numerous, doubtless represent relics of ranges that are matters of geological history where by some remarkable accident the fungi in question have not yet surmounted the barriers of climate, ocean, mountains, or other restricting factors. When fungus provinces or zones are charted as has been done so well for higher plants and animals one such zone in America will be found to extend from Argentina to New England. Other ranges will be recognizable for fungi which do not conform to the usual life zone pattern and often present startling contrasts to them.

COSMOPOLITANISM

The fact that many species of fungi are practically world-wide has been mentioned earlier. In fact, cosmopolitanism is so commonplace that the taxonomist of fungi does not use a local flora to identify his plants, but must have recourse to the whole of the world's mycological literature if he would be even approximately correct. Hence it is that students of fungi have so little respect for the lists of new species that have often been proposed for each new region.

CONCLUSION

Compared with the available information regarding the geography of seed plants evidences of a reasonable mycogeography appear inadequate. From the mass of detailed records, however, some of the problems that arise in mapping the fungus vegetation of the world can be recognized and some conclusions arrived at if only tentatively:

Life zones bounded by climatic lines, although significant for part of the mycoflora, are chiefly recognizable for those species which require particular substrata which in themselves are dependent upon climate, although climatic limits for many non-obligate saprophytes are also in evidence.

Endemic species make up provinces not in accord with the life zones noted for higher plants and animals perhaps as a result of the geological history of those species complicated by the question of barriers. Delimitation of all areas of distribution is obscured by the general presence of cosmopolitan species.

These two types of provinces, life zone and endemic, are both bounded by barriers of climate, ocean, mountains, deserts, wind direction, lack of bridging hosts or vectors and possibly affected by parasites and other deleterious organisms. But through the influence of man with his mechanized civilization these barriers are now being crossed by many fungi with resultant new practical problems for the mycologist whether he is concerned with industry or with animal or plant pathology.

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ENTOMOLOGY.—*The North and Central American spider parasites of the genus* Pseudogaurax (*Diptera: Chloropidae*).[1] DAVID G. HALL, Bureau of Entomology and Plant Quarantine. (Communicated by C. F. W. MUESEBECK.)

Black widow spiders (*Latrodectus mactans* F.) have received much attention in the daily press of the United States during the past several years, and parasites of these spiders have become of general interest. Reproductions of photographs showing biological phases in the life history of one of these parasites of the black widow spider have received wide circulation in two popular monthly magazines, under an erroneous name.

The life history of no species of *Pseudogaurax* has been studied fully. The egg, larva, pupa, and adult of *Pseudogaurax anchora* Loew were figured by Howard.[2]

Eggs of some species belonging to this genus are known to be deposited upon the silken strands of egg sacs of spiders, on the cocoons of lepidopterous insects, or on egg masses of mantids. The larvae penetrate the coverings and destroy the contents. When full grown the larvae pupate within the cocoon or egg mass, or on the silk of the egg sac.

The late F. W. Stickney of the Bureau of Entomology and Plant Quarantine, during his investigations in southern California found cocoons of the black widow spider to be highly parasitized by *Pseudogaurax signatus* Loew. This species has been reared many times from egg sacs of the black widow spider in numerous localities in the southern part of the United States.

A key to separate the known North American and Central American species of *Pseudogaurax*, descriptions of four previously undescribed species, and illustrations of the dorsal thoracic color markings of seven species are presented herewith. The material upon which this paper is based is all in the U. S. National Museum.

PSEUDOGAURAX Malloch

Pseudogaurax Malloch, 1915, Proc. Ent. Soc. Wash. 17: 159 (not Duda, 1930). (Genotype, *Gaurax anchora* Loew, by original designation.)

As pointed out by Malloch[3] in his key, the genus *Gaurax* previously included two distinct groups, one with the scutellum rounded and convex and the other with the scutellum elongate and dorsally flattened. For the group

[1] Received March 13, 1937.
[2] HOWARD, L. O. *The insect book*, p. 184, fig. 106, 1902.
[3] MALLOCH, J. R. Can. Ent. 46: 116. 1914.

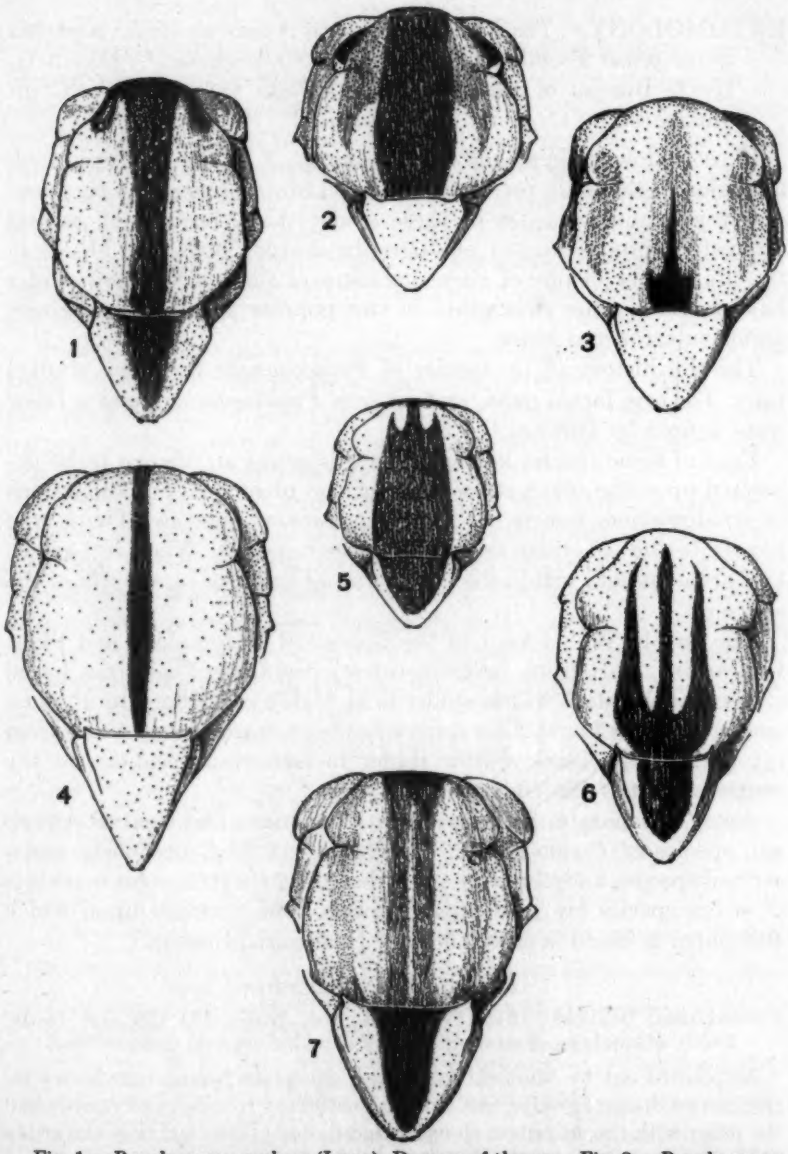


Fig. 1.—*Pseudogaurax anchora* (Loew). Dorsum of thorax. Fig. 2.—*Pseudogaurax misceomaculata*, n. sp. Dorsum of thorax. Fig. 3.—*Pseudogaurax lancifer* (Coq.) Dorsum of thorax. Fig. 4.—*Pseudogaurax unilineata*, n. sp. Dorsum of thorax. Fig. 5.—*Pseudogaurax latimaculata*, n. sp. Dorsum of thorax. Fig. 6.—*Pseudogaurax lyrica*, n. sp. Dorsum of thorax. Fig. 7.—*Pseudogaurax signata* (Loew) Dorsum of thorax.

of species with the convex scutellum he erected the genus *Neogaurax*, with *Gaurax montana* Coq. as genotype. Discovering later (1915) that he had renamed the typical *Gaurax*, he named the group with the elongate scutellum *Pseudogaurax*, with *G. anchora* Loew as genotype, synonymizing *Neogaurax* with *Gaurax*.

Generic characters.—Head. Eyes with long pile, higher than long, emarginate posteriorly; frontal triangle with a single marginal row of setae; front irregularly setose; parafrontals each with a row of setae near eye, these descending nearly to the antennal insertion; bucca short and with a row of rather long setae along edge; epistoma slightly protuberant; clypeus slightly depressed; antenna with first segment short, second segment about 4 times as long as first and with long hair, especially along the inner edges, and a single longer seta dorsally; third segment ovate, higher than long, covered with abundant, short, curling hair; arista short plumose throughout its length, the rays from 2 to 4 times as long as the greatest diameter of the style; inner vertical bristles 1; outer vertical bristles 1, long and distinct; ocellar bristles reclinate. *Thorax* thickly covered with long, scattered, light-colored hair; posthumeral bristles arranged 1:2; postalar bristle 1. Scutellum flattened above, elongate, and ending in an obtuse point, with long apical setae arising from protuberant bases near the apex. *Wing* with costa extended to tip of fourth vein, fifth vein with a distinct flexure. *Legs* rather densely hairy, the hind tibia with an oval, smooth, velvety (sensitory?) area on the inner side.

As stated above, the genus *Pseudogaurax* differs from *Gaurax* in that the scutellum is elongate and flattened above, ending in a more or less obtuse point and with elongate apical bristles situated on approximated tubercles. In additon to these differentiating characters, the scutellum lacks elongate marginal setae. The genus differs most obviously from *Eugaurax* Malloch, in that *Eugaurax* has the posthumeral bristles arranged 2:3 or more, never 1:2 as in *Pseudogaurax*.

The species of *Pseudogaurax* that fall here are exceedingly similar in many respects and differ mainly in thoracic maculation and in thoracic proportions. These characters are so obvious that I have figured the dorsum of the thorax of each species.

Pseudogaurax Duda is distinct from and preoccupied by *Pseudogaurax* Malloch. The following disposition of it is made:

MIMOGAURAX, new name

Pseudogaurax Duda, 1930, Folia Zool. Hydrobiol., 2 (3): 86. (Preoccupied by *Pseudogaurax* Malloch, 1915.) Genotype, *Gaurax interruptus* Beck.

KEY TO SPECIES OF PSEUDOGAURAX FROM NORTH AMERICA AND CENTRAL AMERICA

1. Scutellum dorsally clear yellow 2
   Scutellum with black markings dorsally 4
2. Dorsum of thorax with wide, blackish brown, longitudinal maculations, small lateral presutural spots, the latter more or less connected to the broad central stripe by infuscated areas. Thoracic length, scutellar

length, and thoracic width in the proportion of 23:7.5:20. Puerto Rico ..... *misceomaculata*, n. sp.

Dorsum of thorax with a single mid-dorsal longitudinal stripe 3

3. Mid-dorsal longitudinal stripe of thorax not extending full length of thorax and broadening more or less before scutellum. Thoracic length, scutellar length, and thoracic width in the proportion of 25:8:19. Puerto Rico, West Indies ..... *lancifer* Coq.

Mid-dorsal longitudinal stripe of thorax extending full length of thorax and narrow throughout. Thoracic length, scutellar length, and thoracic width in the proportion of 33:11:22. Panama ..... *unilineata*, n. sp.

4. Mid-dorsal longitudinal stripe of thorax relatively narrow, broadening anteriorly and extending into two shorter lateral stripes which do not reach posteriorly to the suture. Thoracic length, scutellar length, and thoracic width in the proportion of 28:8:18. Mass., Md., Va., Fla., O., Ind. ..... *anchora* Loew

Color pattern of thorax not as above 5

5. Dorsum of thorax with a single, wide, longitudinal stripe. Thoracic length, scutellar length, and thoracic width in the proportion of 15.3: 4.5:11.25. Panama ..... *latimaculata*, n. sp.

Dorsum of thorax with more than one longitudinal stripe 6

6. Dorsum of thorax with three longitudinal stripes in the shape of an inverted fork or the frame of a lyre. Thoracic length, scutellar length, and thoracic width in the proportion of 27:8:18. Costa Rica ..... *lyrica*, n. sp.

Dorsum of thorax variable, usually with several indistinct, reddish orange to brown, longitudinal stripes, the scutellum always with a well-defined, dark-brown to black, dorsal spot. Thoracic length, scutellar length, and thoracic width, in the proportion of 30:11:20. Calif., Tex., Tenn., N.C., Va., Md., Mexico ..... *signata* Loew

Pseudogaurax anchora (Loew)

Gaurax anchora Loew, 1866, Cent. 7 (94): 51; Williston, in Forbush and Fernald, 1896, Report on Gypsy Moth, p. 387; Coquillett, 1898, Bull. 10: 71, n. ser., Div. Ent., U. S. Dept. Agri.; Howard, 1902, Insect Book, p. 184, fig. 106; Williston, 1908, Manual of North American Diptera, p. 311; Becker, 1912, Mon. Chlor. 4: 75; Johnson, 1913, Dipt. Fla., p. 87; Psyche 20: 35.

Pseudogaurax anchor [Loew], Malloch, 1915, Proc. Ent. Soc. Wash., 17: 159; Johnson, 1925, Proc. Bost. Soc. Nat. Hist., p. 99; Auten, 1925, Ann. Ent. Soc. Amer. 18: p. 244; West, 1928, N. Y. State List Ins., p. 861.

Male and female.—*Head* yellow; eyes reddish brown; arista and ocellar spot black. *Thorax* yellow, dorsum of thorax with brownish-black maculations as in Fig. 1; postscutellum black. *Abdomen* dorsally with first segment yellow, posterolaterally dark brown; second segment laterally dark brown to black, third and fourth segments dark brown to blackish laterally, sometimes lighter; venter yellow. *Wing* hyaline, veins yellow; haltere lemon yellow. *Legs* whitish yellow.

Type.—In the Museum of Comparative Zoology, Cambridge, Mass.

Remarks.—The National Museum collection contains 1 female, Weston, Mass., July 23, 1911; 1 female, Beverly, Mass., Aug. 27, 1909; 2 females, Rock Ledge, Fla., Feb. 6 (C. V. Riley); 2 females, Riggs Mill, Ind., May 15,

1914, "ex cocoon *promethea*" (G. W. Barber); 1 female, Hagerstown, Md., Aug. 2, 1918, "in cocoon of *Heterocampa leucostigma*" (Pennington); 1 female, Falls Church, Va., May 15 (Banks); 2 males and 4 females, Falls Church, Va., Jan. 26, 1930, "from cocoons of *promethea*" (Cushman).

This species has been reared upon numerous occasions from lepidopterous cocoons but whether it is a parasite or a scavenger has not been ascertained. All of the reared specimens in the National Museum collection were reared from cocoons of Lepidoptera. The notes upon such specimens indicate that the collectors believed the species to be parasitic.

Pseudogaurax misceomaculata, n. sp.

Male.—Like *anchora* except as noted in the key and in thoracic maculations as illustrated in Fig. 2. The species also differs from *anchora* in having a brownish black anterior and a smaller posterior mesopleural spot, in having the postscutellum decidedly glossy black with a smaller darkened area laterally, and in having the abdomen almost black.

Type locality.—Bayamon, Puerto Rico.

Type.—United States National Museum no. 51942.

Remarks.—One male labelled "on leaves of *Flamboyan,*" Jan. 28, 1934 (San Juan accession no. 5135B), collected by C. G. Anderson.

Pseudogaurax lancifer (Coq.), n. comb.

Gaurax lancifer Coquillett, 1900, Proc. U. S. Nat. Mus. 22: 265; Becker, 1912, Mon. Chlor. 4: 76; Wolcott, 1923, Ins. P. R., p. 232; 1927, Ent. D'Haiti, p. 329; Duda, 1930, Folia Zool. Hydobiol. 2 (1): 87.

Male and female.—As in *signatus* except as noted in key and in maculations of the thorax as illustrated in Fig. 3. It also differs from *signata* in having the arista black, in possessing an additional brown spot on the posterior part of the mesopleura, in having the postscutellum but slightly darkened, and in having the legs clear light lemon yellow.

Type.—U. S. National Museum no. 4384.

Remarks.—The National Museum collection contains the type-series of 8 specimens "from spider's eggs," Puerto Rico, Feb. 9, 1899 (Busck), and 5 specimens "from spider's eggs," Montserrat, West Indies, March 16 (Hubbard); also 5 specimens, "spider parasites," Port Cangrejos, Puerto Rico, June 1, 1920 (Wolcott), and 1 specimen "on guava leaf," Barceloneta, Puerto Rico, Apr. 25, 1933 (Mills and Anderson).

This species appears to have much the same type of biology in the West Indies as *signata* has in the United States. It was reared in Puerto Rico in considerable numbers from the egg clusters of the spider *Gasteracanthia cancriformis* by G. N. Wolcott and forwarded to the National Museum under his accession number 333–21.

Pseudogaurax unilineata n. sp.

Male and female.—Like *signata* except as noted in the key and in thoracic maculations as illustrated in Fig. 4. It further differs from *signata* in having the aristal style yellowish, the anterior mesopleural spot more diffused and extended over a wider area, the tibiae more decidedly brownish, and also in the maculations of the yellow abdomen which are as follows: First segment

yellow except for posterolateral darkened spots; second segment with larger posterolateral areas; third segment dark brown to black; fourth segment anterolaterally yellow, posterior margin yellow; venter entirely yellow.

Type locality.—Canal Zone, Panama.

Type.—Female, United States National Museum no. 51943.

Remarks.—Described from a holotype female and 13 paratype male and female specimens reared "from spider's nest," Ancon, Canal Zone, Panama, Oct. 20, 1923 (Zetek), and 1 paratype specimen, Alhajuelo, Canal Zone, Panama, March 18, 1912 (Busck).

Pseudogaurax latimaculata n. sp.

Male and female.—Like *anchora* except as noted in the key and in thoracic maculations as illustrated in Fig. 5. The species also differs from *anchora* in having the ocellar spot more extensive, in the postscutellum, which is yellow, and in the second, third and fourth abdominal segments of the abdomen, which are dark brown to black.

Type locality.—Alhajuelo, Panama.

Type.—Female, United States National Museum no. 51945.

Remarks.—Described from the holotype female and 1 paratype male collected March 12, 1912, Alhajuelo, Panama (Busck).

Pseudogaurax lyrica, n. sp.

Male and female.—Like *signata* except as noted in the key and in the light and dark pattern on the dorsum of the thorax as illustrated in Fig. 6. Also, the postscutellum is yellow, not brown or black, the wing veins are dark, not yellow, the legs are clear lemon yellow, and the abdomen is distinctly blackened.

Type locality.—Higuito, San Mateo, Costa Rica.

Type.—Female, United States National Museum no. 51944.

Remarks.—Described from the holotype female, and 4 paratype male and female specimens collected in Costa Rica by Pablo Schild.

Pseudogaurax signata (Loew), n. comb.

Gaurax signatus Loew, 1876, Zeitsch. Ges. Naturwiss., p. 338; Becker, 1912, Monogr. Chlor. **4**: 75; Duda, 1930, Folia Zool. Hydobiol. **2**: 87.

Gaurax araneae Coquillett, 1896, Ent. News, **7**: 320; 1896, Bull. **10**: 72, n. ser. Div. Ent., U. S. Dept. Agr.

Gaurax signatus var. *mallochi* Duda, 1930, Folia Zool. Hydobiol., **2** (1): 87.

Male and female.—*Head* yellow, eyes reddish brown; ocellar spot black; arista dark brown. *Thorax* yellow; reddish brown to brownish black dorsal maculations usually as illustrated in Fig. 7, but sometimes also with a small dark posthumeral spot; mesopleura with a single brownish black spot anteriorly; postscutellum usually darkened centrally, sometimes light brown, but rarely blackened. *Abdomen* with first segment medianly yellow, laterally dark brown; second segment dark brown, sometimes lighter anteromedianly; third segment dark brown with yellow posterior margin; fourth segment dark brown with yellow posterior margin, sometimes lighter laterally; venter yellow. *Wings* clear, veins yellowish. *Legs* yellow, tibiae sometimes and tarsi usually darker yellow to brown dorsally.

Type.—In the Museum of Comparative Zoology, Cambridge, Mass.

Remarks.—In the United States National Museum there are nearly 60 specimens of both sexes of this species. Most of these have been reared from

the egg sacs of *Argiope riparia*, or from *Latrodectus mactans*, although many records read only "from spider's nest." This species has been reared several times from mantid egg masses (Brownsville, Tex., by Vickery and St. Lucrecia, La Oaxaquena, Mexico, Sept. 1911, by Ulrich).

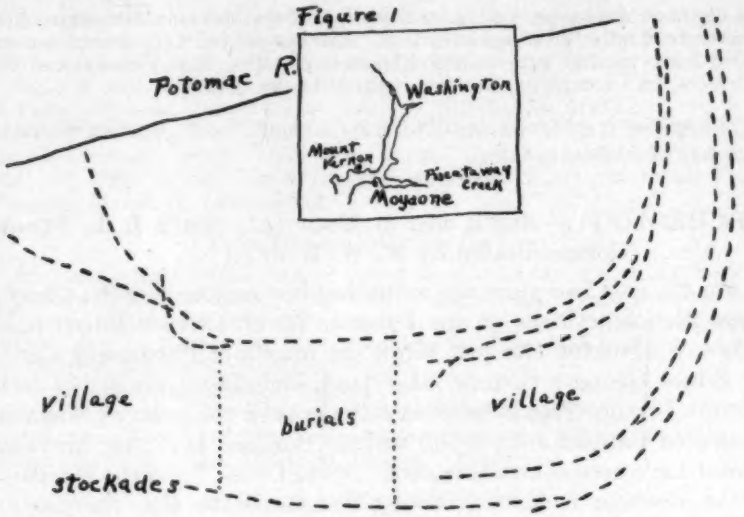
The species is evidently distributed throughout North America wherever *Latrodectus mactans* occurs.

ARCHEOLOGY.—*Burial area in Moyaone.*[1] ALICE L. L. FERGUSON. (Communicated by W. W. RUBEY.)

For the past two years the writer has been excavating the site of a large Algonkin village on the Potomac River, about eighteen miles below Washington and just below the mouth of Piscataway Creek, in Prince George's County, Maryland, and diagonally across from Mount Vernon. This is believed to have been the town of Moyaone shown on Captain John Smith's map.[2] Bozman[3] says that Moyaone "must have been somewhere about Broad Creek," and the *Handbook of the American Indians*[4] following Bozman, states that the location of Moyaone "was about Broad Creek." Bozman made his identification on the basis of the Smith map and apparently confused Broad Creek, which is further up stream, with Piscataway Creek. Broad Creek is little more than a bay on the river, while Piscataway Creek is wide for a considerable distance, has many little bays and tributaries and enters the Potomac at the bend just as the Smith map indicates. Mooney,[5] on the other hand says, "Moyaones appears, on the same map, to have been directly opposite (Tauxenent or Mount Vernon), on the Maryland side, just below the mouth of the Piscataway Creek." On Smith's map, Moyaone is diagonally across from Tauxenent. Thomas Jefferson,[6] in his table giving the situations of the Virginia villages, places Tauxenent in Fairfax County "about General Washington's." The Broad Creek site is not opposite Mount Vernon or Tauxenent.

Nacotchtank, shown on the Smith map, was latinized by the Jesuits into Anacostia which it is still called although now a part of the city of Washington. This makes a convenient tie point. It is futile to at-

[1] Received March 10, 1937.
[2] A copy of this map may be seen in Edward Arber's edition of Captain John Smith's works, 1608–1631. The English Scholar's Library, Birmingham, 1884.
[3] BOZMAN, JOHN LEEDS. *History of Maryland.* 1: 119. Baltimore, 1837.
[4] *The Handbook of the American Indians.* Bur. Amer. Ethn. Bull. 30 (pt. 1): 953. 1907.
[5] MOONEY, JAMES. *Indian tribes of the District of Columbia.* Amer. Anthropologist 2 (3): 259. 1889.
[6] JEFFERSON, THOMAS. Notes on the State of Virginia, p. 152. London, 1787.



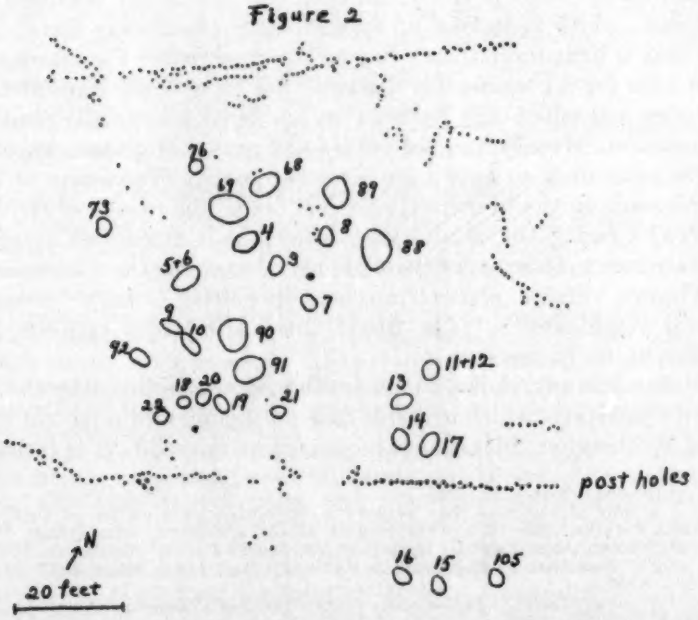


Fig. 1.—Sketch map of Moyaone showing the stockade lines and inset giving the location. Fig. 2.—Burial area in Moyaone.

tempt to make accurate measurements on a 17th century map but it is of interest that the measurement on the Smith map from the point in Virginia where the Eastern Branch flows into the Potomac opposite Nacotchtank, to Moyaone, is 3¼ marine leagues. The modern value of a marine league is 3.45 statute miles which makes the distance about 12.9 miles and the measurement on the modern map from the same point to the site is 11.7 miles while the Broad Creek site is only 8½ miles. This placing of Moyaone near and below Piscataway Creek is further verified by four other early maps, "A Chart of Virginia" 1608, the "Simancas Map" 1610, "Belgii Novi, Angliae Novae et Partis Virginiae Novissimi" published about 1650 and the map of Johannes Vingboons published about 1665. Other historical evidence tending to identify this site as Moyaone is given in a manuscript on the history of the tribe now ready for publication. Moyaone was probably burned by the Virginians in 1623.

The site is a large one and was occupied for a long period. There is a great deal more work to be done and a final report must await the completion of the excavations. Work so far done indicates two periods of occupation. The site was first occupied by a large settlement of people about whom very little is known. They made the Popes Creek type of pottery—probably the earliest in this region—described by William H. Holmes[7] in his report on the pottery of the Eastern United States. This pottery is very common in the Potomac valley and is also found along the coast from the Carolinas through New England. In the current terminology this culture is called the Coastal Focus. Though the later occupants of Moyaone made pottery of another type, the Popes Creek ware and associated artifacts occurred in isolation over a considerable area beginning a hundred feet or more from the edge of the later site.

After the makers of the Popes Creek ware came a group of people whose pottery, according to William A. Ritchie[8] of the Rochester Museum of Arts and Sciences, corresponds to that of the third Algonkin period of culture in New York. Dr. Ritchie very kindly made a visit to the site and verified what is here called third Algonkin. The Popes Creek pottery is frequently yellow but usually red, and it is always very coarse with a grit or sand temper (Fig. 4). The third Algonkin pottery is all shades of gray and black, rarely red and yellow and it is tempered with ground up potsherds, clam shells, quartz,

[7] HOLMES, WILLIAM H. *Aboriginal pottery of the eastern United States.* Bur. Amer. Ethn. Ann. Rept. 20: 153. 1903.

[8] RITCHIE, WILLIAM A. *Algonkin sequence in New York.* Amer. Anthropologist 34 (3): 406–414. 1932.

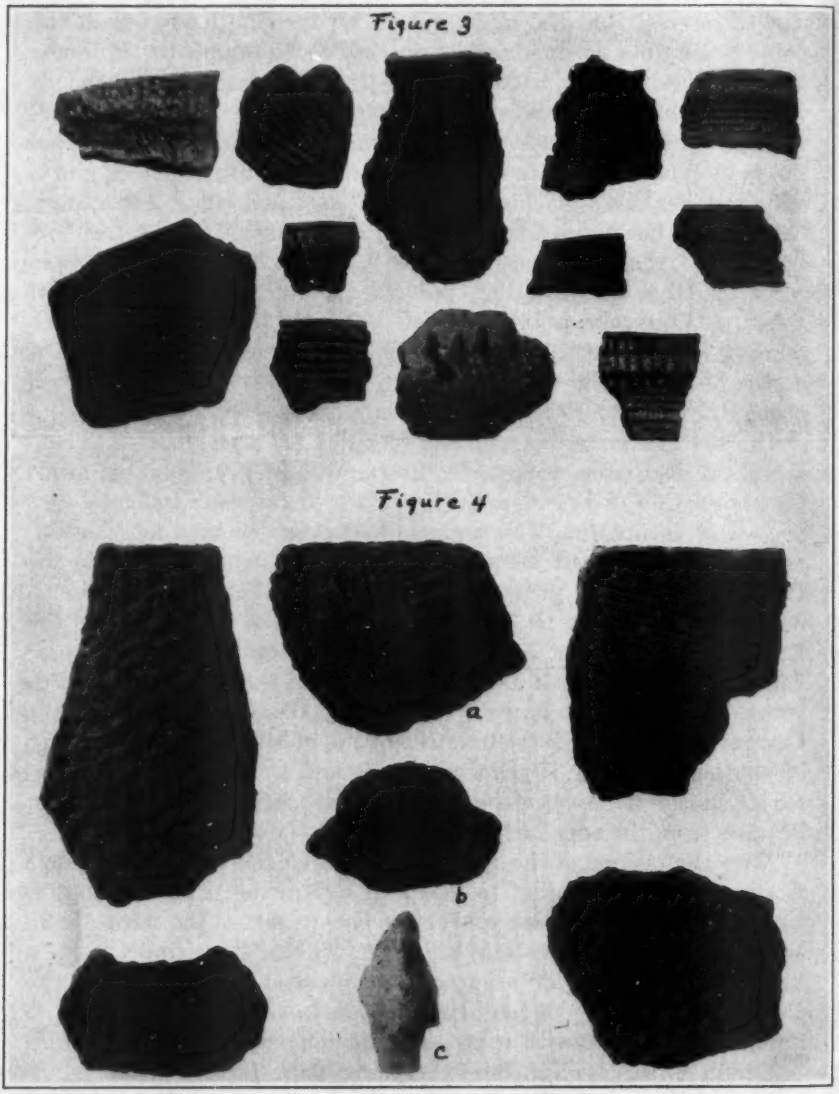


Fig. 3.—Third Algonkin pottery. Fig. 4.—Popes Creek pottery. a, a conical base; b, a lug, one of two found at the site; c, arrow point found in skull of No. 16.

sand and mica (Fig. 3). Occasionally the paste is so smooth that no temper is evident. This later pottery carries somewhat more ornamental designs than the earlier, especially around the rims of the pots, a few of which display real beauty, though many were badly made. Inside the stockades of the village, almost all the pits had a mixture of both types but a few pits were found that had only the third Algonkin.

Moyaone was in the shape of a huge crescent, the points of which, nearly four hundred feet apart, touched the Potomac River. Inside the stockades the ground was peppered with post holes. In the center of the crescent, at its broadest part, there were no post holes and no signs of village activity. The refuse pits and the pottery fragments, broken pipes and stone artifacts that had been scattered in every direction up to that point stopped, and instead of them twenty burials were found. The burials belonged to the earlier people, yet the later inhabitants of Moyaone, with a large population crowded into a restricted area, knew of the burials and respected them.

The only pottery found associated with the burial pits was of the Popes Creek type. All the bones were so far decayed that only thirteen of the twenty skeletons were in any way identifiable. Out of these thirteen, all were females except one, No. 3, which was that of a middle aged male with a large scar on the skull. Of the twelve females, six were middle aged, two were old, and four were young adults. It is unfortunate that even these thirteen were for the most part too poorly preserved to make it possible to obtain measurements. Dr. T. D. Stewart of the U. S. National Museum very kindly made the measurements given here and the writer would like to express her thanks to him:

No. 3, male, skull length 19.4 cm. No. 5, cephalic index 80.22; orbital index 92.5; nasal index 48.08. No. 6, skull length 18.2 cm. No. 7, jaw measurements; height of symphysis 3.1? cm; length of lower jaw 9.4 cm; breadth minimum of the ascending ramus 3.8 cm. No. 11, skull length about 18.8 cm, probably dolichocephalic. No. 12, probably brachycephalic. No. 13, skull length 17.4 cm; skull height 13.3 cm, meso- to dolichocephalic. No. 14, cephalic index 73.2; facial index 51.6; nasal index 54.3; orbital index 86.1; alveolar index 116. No. 20, very dolichocephalic. No. 21, head index below 70; head height measurable 13.6 cm.

Of these, four are dolichocephalic, one meso- to dolichocephalic, and two brachycephalic.

Three of the burials were grouped. No. 5, an aged female, lay directly over No. 6, a middle aged female. No. 9 seemed to be a secondary burial, it consisted of the fragmentary bones of two individuals, a child of between six and eight years of age and an adult.

Nos. 11 and 12, an old and a middle aged female, were buried side by side and so close together that it was impossible to determine which bones belonged to which skeleton.

A total of 44 random potsherds and 4 arrow points were found in the grave pits exclusive of an arrow point found at the base of the skull of No. 16 and fragments of a very large pottery jar found directly under the knee of No. 14. No other fragments of this jar were found in the pit although several small pieces of it were found fifty feet away. In the far corner of the pit of No. 16 was found a group of sherds that fitted together and were very like the fragment found with No. 14. Aside from the charcoal which was always present, and a small stone 3½ inches long smeared with red iron oxide paint, these were the only artifacts found in the burial pits.

Most of the burials, especially Nos. 4, 8, 10, 15, 16, 17 and 19 were in such poor condition that there was almost nothing left. Nos. 15, 16, 17, and 19 consisted only of jaw fragments and teeth, all so poorly preserved that they powdered at a touch. In this group of burials were seven pits, Nos. 68, 69, 88, 90, 91 and 92, which were completely empty. The pits were sharply defined and they contained the same charcoal flakes and the same brown discolored soil that marked the burial pits. They had scattered in them a total of 14 potsherds of the Popes Creek ware. It seems probable that these pits were also burial pits in which the bones had completely disintegrated.

The burials were all of about the same depth. Most of them were about 1.9 feet from the surface to the highest point of the burial. The shallowest burial, No. 9, was just under the plow line, a little less than a foot below the surface, and the deepest, No. 13, began at 2.35 feet.

All the pits had small flakes of charcoal scattered through them. Nos. 73, 76 and 105 were shallow fire pits. Nos. 73 and 76 contained a few deer bones and potsherds. On one side of fire pit No. 105 was the charred remnant of a small post about two inches in diameter, extending to a depth of 3.4 feet below the surface. These fire pits near the graves, containing the same type of pottery, suggest feasts and fires connected with the burial ceremonies. In the entire burial area, in addition to the sherds already mentioned which were more intimately associated with the burials, there were 170 sherds of the Popes Creek type scattered around generally and only 16 rather small sherds of the third Algonkin period.

Attention should be called to the large post hole, a foot in diameter,

in the center of the burial area. No. 3, the only male burial found, was near the pole and the other burial pits tend to encircle it.

Only a few general customs appear from a study of this group of burials. The bodies were buried individually and they were flexed. There was no effort towards orientation. About half of the skeletons rested on the right side, and half on the left. With the exception of the pottery fragment found in burial No. 14 and possibly the fragment in No. 16, there were no mortuary offerings. The objects found in the other pits could easily have slipped in when the pits were being dug and filled.

The surprising thing about this burial area in the center of a crowded village, was that in it were found only sixteen sherds belonging to the later period of occupancy. It is remarkable that any taboo could have been sufficiently strong to hold an area as large as this unprofaned in the midst of all the village activities of a later settlement.

Obituary

OZNI PORTER HOOD, retired, Chief Mechanical Engineer of the Bureau of Mines, Washington, D. C. and former Chief of its Technologic Branch, died at his home in Washington April 22, 1937. The son of an inventor, born in Lowell, Massachusetts, on June 14, 1865, he was educated in mechanical engineering at Worcester and Rose Polytechnic Institutes, receiving the degrees of B.S., M.S., and M.E. He began his career as a pattern maker but shortly became a member of the faculty at Kansas Agricultural College and then at the Michigan College of Mines.

Dr. Hood joined the Bureau of Mines at its Pittsburgh Experiment Station in 1911. He assumed charge of the fuel investigations which had started in 1904 at the World's Fair in St. Louis and continued by the U. S. Geological Survey prior to the formation of the Bureau of Mines on July 1, 1910. He coordinated this work and developed mechanical and electrical engineering research pertaining to safety in mines. From small beginnings he organized a system for testing and approving, with respect to safety and efficiency, electrical equipment for use in gassy coal mines. The Davis multiple-unit calorimeter, the Burrell gas detector, and the Gibbs oxygen breathing apparatus are early examples of his mechanical genius. He made a pioneering study of gasoline mine locomotives in relation to safety and health.

With his co-workers he conducted fundamental research on the mechanism of combustion in fuel beds and participated in the practical development of the combustion of powdered coal and initiated timely studies on the gasification of coal. The publications on lignite and peat in which he participated still remain the outstanding documents on these subjects, although written many years ago. In the conduct of these investigations he designed and built a simple unit for carbonizing lignite. He directed smoke abatement investigations in various cities; carried out nation-wide sampling of coal

and its analysis in connection with Government purchases of coal on specification; and made very substantial savings of heat and power in Government plants.

Dr. Hood was made a life member of the American Society of Mechanical Engineers in 1935, and in 1932 his Alma Mater, Rose Polytechnic Institute, conferred on him the honorary degree of Doctor of Engineering. In addition to membership in Tau Beta Pi, he belonged to the Cosmos Club, Washington, D.C., The Washington Society of Engineers, the Washington Academy of Sciences, the American Society of Mining and Metallurgical Engineers, the International Railway Fuel Association, and he became an honorary member of the American Society of Heating and Ventilating Engineers.

WILLIAM MORTON WHEELER, emeritus professor of entomology, Harvard University, died at Cambridge, Mass., April 19, 1937.

Professor Wheeler was born at Milwaukee, Wis., March 19, 1865. He attended Engelmann's German Academy in Milwaukee, and graduated from the German-American Normal School of that city. He received the degree of Doctor of Philosophy from Clark University in 1892, then studied for a year at Würzburg, Liege and the Naples Zoological Station. From 1894 to 1899 he was instructor and assistant professor of embryology at the University of Chicago, and from 1899 to 1903, professor of zoology at the University of Texas. During the next five years he was curator of invertebrate zoology at the American Museum of Natural History, but in 1908 accepted the appointment of professor of economic entomology at Harvard University. From 1915 until 1929 he was dean of the Bussey Institution, a graduate school of the University for research in applied biology; in the year 1924–1925 he was exchange professor to the University of Paris; and from 1926 he was professor of entomology at Harvard University and associate curator of insects at the Museum of Comparative Zoology.

Professor Wheeler's chief interest was the classification and behavior of ants, but his bibliography, which contains 467 titles, includes also such subjects as embryology, evolution, parasitism, and animal sociology in general. His studies in sociology led him into psychology and philosophy, on which he published numerous papers. Several of his works appeared in book form, such as *Ants*, *The social insects*, *Foibles of insects and men*, and *Demons of the dust*. Professor Wheeler wrote with clarity, pungency and humor, as is well illustrated by two of his shorter essays: *The dry-rot of our academic biology* and *The termitodoxa, or biology and society*.

In recognition of his scholarship and contributions to science, many honors were conferred upon him. He received an honorary Sc.D. from the University of Chicago in 1916, Harvard University in 1930, Columbia University in 1933; and an honorary LL.D. from the University of California in 1928. He was awarded the Elliot Medal, and the Leidy Medal from the Philadelphia Academy of Natural Sciences in 1931. In 1934 he was elected an Officer, Legion d'honneur. He was associated with many scientific organizations, including the National Academy, the American Academy, the Washington Academy, the Philosophical Society, the Royal Entomological Society of London, the Société Entomologique de France, and Société Entomologique de Belgique.